VULNERABILITY OF NATIONAL INTERDEPENDENT INFRASTRUCTURE NETWORKS TO SPATIALLY LOCALISED HAZARDS

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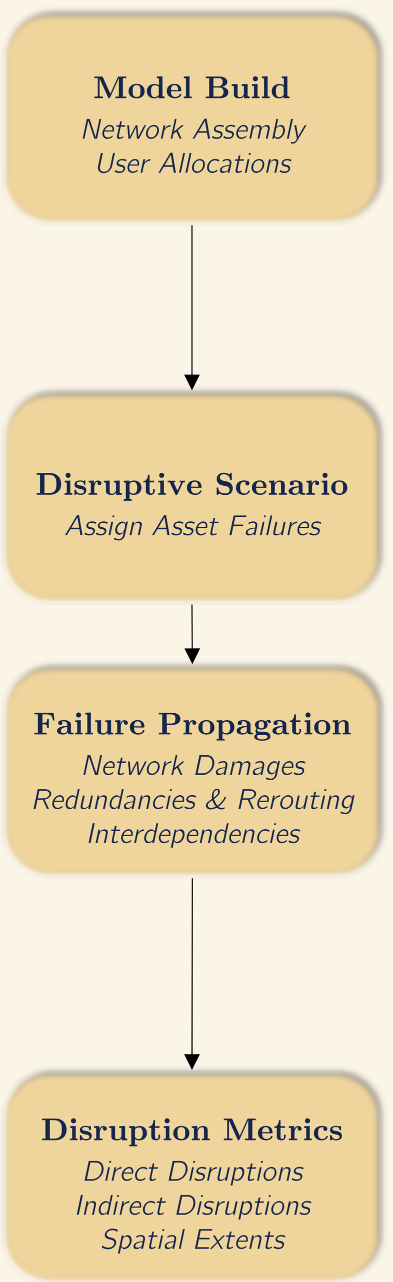
INTRODUCTION

Critical infrastructure networks are geographically distributed systems spanning multiple scales. These networks are increasingly interconnected and dependent on each other for normal operation. Localised asset failures from natural (or intentional) hazards can propagate across multiple networks, greatly increasing the magnitude and spatial extents of disruptions – potentially affecting those far removed from an initiating failure event.

This poster presents an overview of our integrated framework for quantifying and identifying systemic vulnerabilities across multiple connected national infrastructures with application to New Zealand.

ADOPTED FRAMEWORK



Model Build: Spatial infrastructure asset data is assembled across regions to produce national infrastructure networks (*Fig. 2*). Source-sink connectivity paths are mapped within and between networks where functional dependencies exist (*Fig. 1*). User demands are allocated to assets using provided statistics/ catchments/zones and spatial analyses at meshblock resolutions.

Disruptive Scenario: Initial network component failures are assumed based on the spatial intersection with a pre-determined hazard extent.

Failure Propagation: Further network failures (partial or complete) propagate where flow/ functional connectivity pathways are disrupted both within and across networks (*Fig. 1*) after allowing for assumed redundancies and rerouting.

Disruption Metrics: Direct disruptions comprise those initiated from within a network after allowing for redundancies and rerouting of connectivity paths. Indirect disruptions result from failures which are initiated beyond the network in question due to functional dependencies with other networks. The outage extent is delineated by the combined spatial footprints of failed components and dependent users, where known.

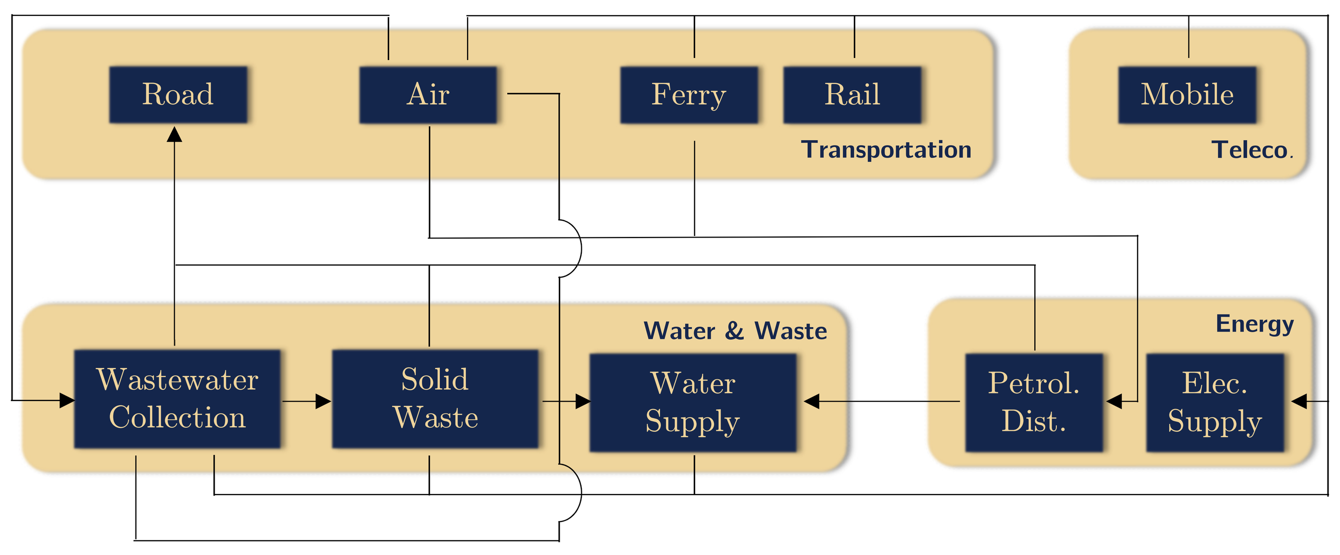


Fig. 1. Directed dependencies for normal operation represented within the New Zealand application. An infrastructure i reliance on infrastructure j is represented as $i \rightarrow j$.

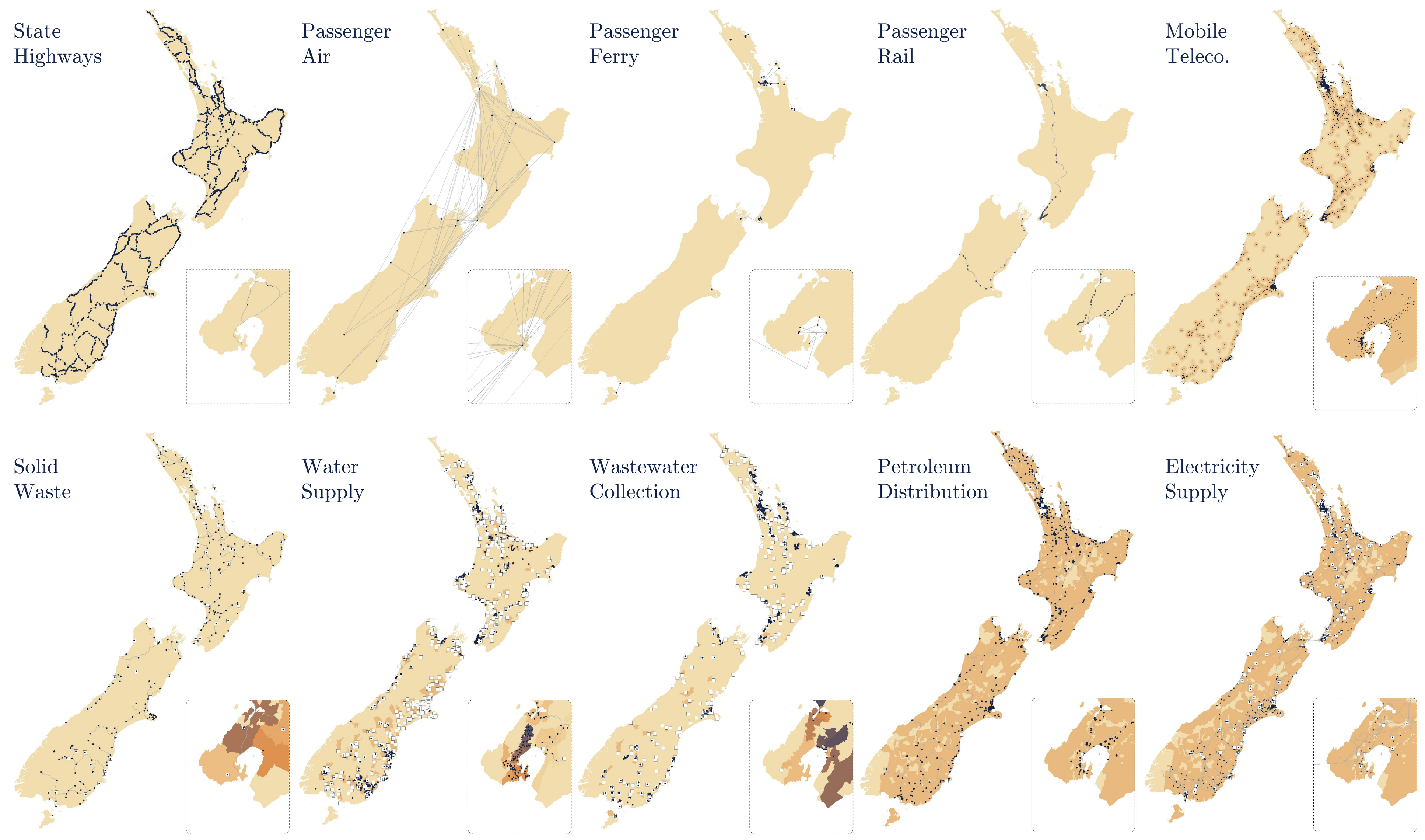


Fig. 2. Representations of the studied infrastructure networks with insets for the Wellington Region. □ represents major service assets (i.e. wastewater treatment plants, water sources, or landfills), ● represents common assets (i.e. pump stations, reservoirs, transfer stations), and ▬ represent the connectivity paths between nodes. Shading delineates the collection catchment or distribution zone extents for nodes. Some nodes, edges, and shading are omitted for clarity.

SIMULATION RESULTS AND VISUALISATION

We divide New Zealand into a tessellated grid of 4590 equilateral hexagon cells to represent spatially localised hazards. Each cell is individually disrupted and disruption metrics are computed according to the outlined adopted framework (*as shown on left*). Aggregating across the simulation set, *Fig. 3* suggests (on average) 54% of the total user disruptions can be attributed to direct network connectivity losses – the remaining being a result of outages initiated through infrastructure dependencies. This highlights the importance for considering interdependencies in quantifying potential disruptions for a specific hazard event and when prioritising resilience building measures. This is especially the case where electricity, road, and water supply networks are involved as these appear to be the leading initiating infrastructures of interdependent disruptions.

Spatially, *Fig. 4* presents the disruptive risk, magnitude x frequency (i.e. the number of user disruptions multiplied by the frequency of which infrastructure network components or populations within the cell are disrupted by other spatially localised hazards) and the reach of disruptions (beyond the host Civil Defence Emergency Management region). As a result, a number of corridors crucial for inter-region infrastructure service are identified such as those feeding into the West Coast and Gisborne Regions. This implies these regions are highly reliant on external service provisions and particularly vulnerable to national disconnection should certain assets within the identified hazard cells fail. The Auckland isthmus is commonly highlighted with significant potential for both frequent and high consequence disruptions with far reaching impacts – notably to Northland and areas of the Waikato Region.

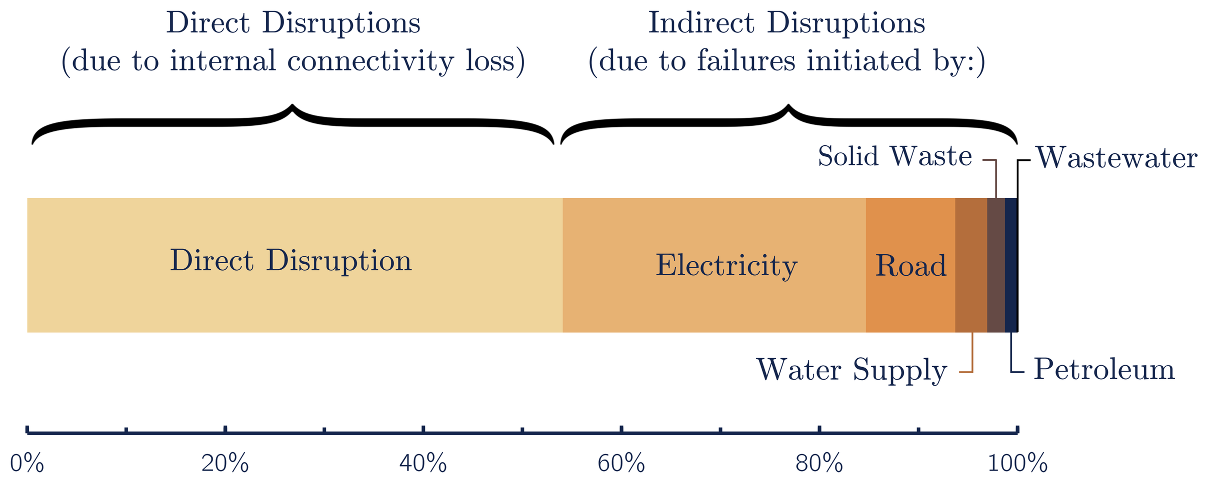


Fig. 3. Proportions of direct disruptions (within each individual network due to connectivity loss) and indirect disruptions (disruptions initiated by an external infrastructure through dependencies).

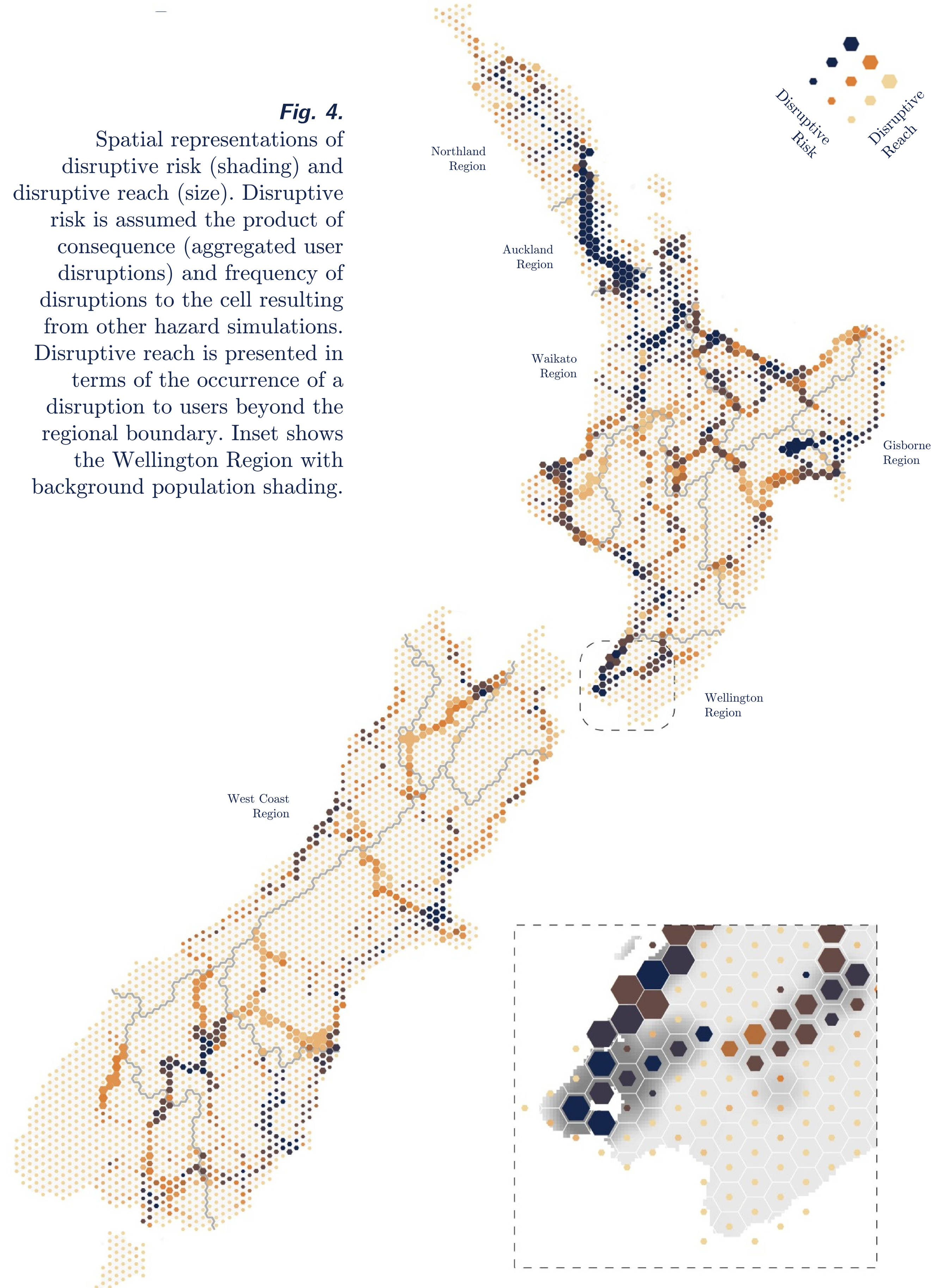


Fig. 4. Spatial representations of disruptive risk (shading) and disruptive reach (size). Disruptive risk is assumed the product of consequence (aggregated user disruptions) and frequency of disruptions to the cell resulting from other hazard simulations. Disruptive reach is presented in terms of the occurrence of a disruption to users beyond the regional boundary. Inset shows the Wellington Region with background population shading.

OUTCOMES

- The presented results highlight the importance for considering dependencies between infrastructures when modelling disruptions at national and regional scales, with the potential to almost double the disrupted population (on average) when compared to modelling infrastructures in isolation.
- We demonstrate there are limitations in restricting infrastructure vulnerability analyses to regional/authoritative boundaries due to the significant reliance on infrastructure network connectivity between many regions.
- While resilience building is important at the component / local asset level, significant benefits may be possible through the introduction of either additional regional infrastructure links increasing redundancy or through more localised infrastructure service provisions – such as distributed electricity generation.
- Further work continues in seeking updated/higher resolution data sets and in the development of infrastructure sector models. In particular, collaborations with Davies et al. [Poster 66] and Liu et al. [Poster 67] to incorporate the recovery and additional quantifiable metrics for national, regional, and specific hazard scenarios such as AF8.

For related outputs, questions, or discussion contact conrad.zorn@ouce.ox.ac.uk